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Impact of Distributed Generation On Distribution Network Stability

Sunkanmi Olajide, Akmal Muhammad
Sheffield Hallam University, Sheffield, South Yorkshire, England

Abstract

Distributed generation (DG) is a significant part of the electric power generation mix around the world. Integrating DG into distribution systems comes with some challenges. The use of battery energy storage systems (BESS) helps mitigate the challenging impact of integrating DG with the grid. In this paper, we modelled and simulated a modified IEEE 9-bus system to evaluate the effects of DG and BESS on grid stability. The system's behaviour was studied under varying disturbances such as switching operations, transient symmetrical fault, and asymmetrical fault. The response of the system to the duration of transient fault was also investigated. The effect of DG and BESS on the total harmonic disturbances of the system was also evaluated. This paper shows that switching of DG does have much effect on the system's stability. However, the switching of BESS introduced some oscillation into the system. The oscillations dampen out eventually. The system was stable under transient symmetrical fault with short duration. The system stability was reduced with the presence of BESS, after the fault was cleared and breakers reclosed. DG improved the harmonics of the systems. However, BESS increased the harmonics in the system

Keywords: *Distributed generation, battery energy storage systems, transient, symmetrical fault, asymmetrical fault, stability, harmonics, oscillation, total harmonic distortion, fundamental harmonics.*

1. Introduction

Lately there has been a growth in the use of distributed generation (DG) around the world. Significant purposes behind this pattern are advancement of electricity markets, environmental concerns, and limitation of constructing new transmission and distribution lines, and ecological concerns [1]. The distributed generation (DG) is a typical decentralized energy system where electricity is generated closer to the users with a potential to increase energy efficiencies and reduce air pollutant emissions dramatically [2]. The DG can be a non-renewable generator such as reciprocating engines, gas turbines, and coal plants or renewable energy generators such as solar photovoltaic, wind, hydroelectric power, and biomass. The notable renewable energy generators are solar or photo-voltaic, wind, and hydro. They come in various capacities and are usually connected to the grid. DG's locations, sizes, and operating power factors all play a role in minimising losses and improve the stability of the system [1]-[3]. The growing interest in DG is balanced by a similar intensive effort committed toward energy storages like ultra-capacitors, flywheels, batteries intermittency and uncertainty of DG sources [4]. The justification of battery energy storage systems (BESS) for diverse applications can be credited to the fact that batteries have medium energy and power densities and react quickly during both charging and discharging cycles [4]-[5]. The merits of applications of BESS include reduction of renewable power fluctuations, load shifting, energy arbitrage benefit, energy management, reduction of peak demand, excess renewable energy management, and power quality improvement [6].

There has been different approach for coordinating variable DG units and energy storage system (ESS) to improve the stability of supply. However, the effect on quality of supply was not considered. [7] presented a paper on an approach for coordinating variable DG units and ESS along with reconfiguration by taking into consideration the economic objectives. [8] proposed, a method called Multi-objective Hybrid Big Bang-Big Crunch (MOHBB-BC) for simultaneous network reconfiguration and power allocation of DGs to solve the problem of uncertainty of the system. [9, 11, 12] provided a multi-objective solution to reduce power losses, improve reliability and voltage stability. They achieved continuous supply however, the quality of supply was not considered.

Power quality is mainly affected by load imbalances, harmonics, sags, and spikes introduced by the distribution system. Power Quality is also becoming an issue for concern due to newer household loads being more sensitive to power quality variations than the equipment used in the past, utility customers are also better educated about issues as interferences, switching transient, and are demanding the utilities to improve the quality of power delivered, and a failure of any unit can have much more importance [3, 13, 14, 15].

Harmonics are not alluring on the grounds that they cause overheating, increased losses, decrease volt-ampere capacity, neutral-line over-loading, mutilate voltage, and current waveforms, and so forth. It is a concern in the modern power system. The frequencies of harmonics are integer multiples of the fundamental frequency. A common way of measuring the level of harmonic distortion in a system is the total harmonic distortion (THD) [16]. THD is the ratio of the RMS value of the harmonic components to the RMS value of the fundamental components [17, 18]. THD is defined by the equation below:

$$THD = \frac{\sum_{n=2}^{\infty} I_n^2}{I_1}$$

THD of voltages and currents in an electrical system needs to be maintained low, often below 5% [15]. It is very important to keep THD low in the power system because the lower the THD the higher the power factor, the lower the peak current, and the higher the system's efficiency.

2. NETWORK MODEL

The modified IEEE 9-bus system model is used to demonstrate the performance of smart grids and ESS in different modes of operation such as island grid-connected and modes. The 230kV, 50Hz system model consists of loads, six (6) transmission lines, and three (3) generators, three (3) transformers, BESS, and DGs as shown below as shown in figure 1 below:

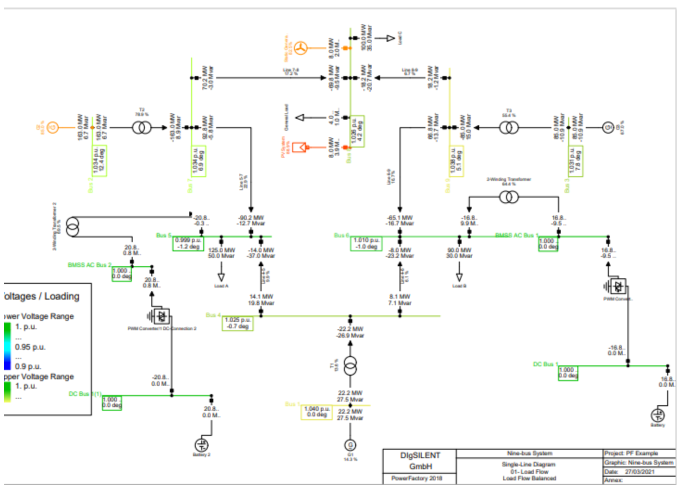

Figure 1: Modified IEEE 9 bus system model

The DG used in this model is the photovoltaic and wind turbine system. The solar system active power is rated 8000KW, and the wind turbine system active power is rated 8MW. DG 1, 2, and 3 with nominal power of 247.5MW, 163.2MW, and 108.8MW are connected to bus 1, 2 and 3 respectively.

Each of the BESS consists of a 0.25kV battery, a 30MVA Pulse Width Modulation (PWM) converter, and a 30MVA transformer.

3. SIMULATION, RESULT AND DISCUSSION

In this work, the response of the system to various disturbances was studied and discussed below:

1.1 Response to switching operation

The behaviour of the bus voltage and power under switching operation is shown in figure 2 and 3 below. The DGs and BESS are isolated at the beginning of the simulation. The wind turbine is closed after 5s, the PV is closed 15s after closing the wind turbine, one of the BESS systems comes ON 15s later and the second BESS system is closed after 25s.

Figure 2 shows the bus voltages per unit. There is a slight increase in the bus voltages when the DGs were switched ON and sharp voltage drops when the BESS was turned ON. However, the bus voltages build up gradually due to decrease in load as it gets charged.

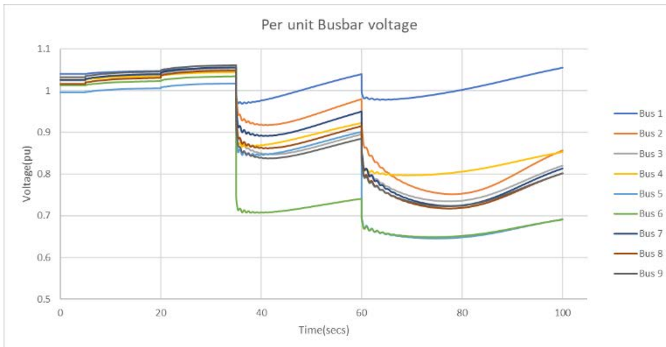

Figure 2: Per Unit Bus bar voltage

Oscillation was also noticed in the system when the BESS was turned ON. However, the oscillation dampens quickly.

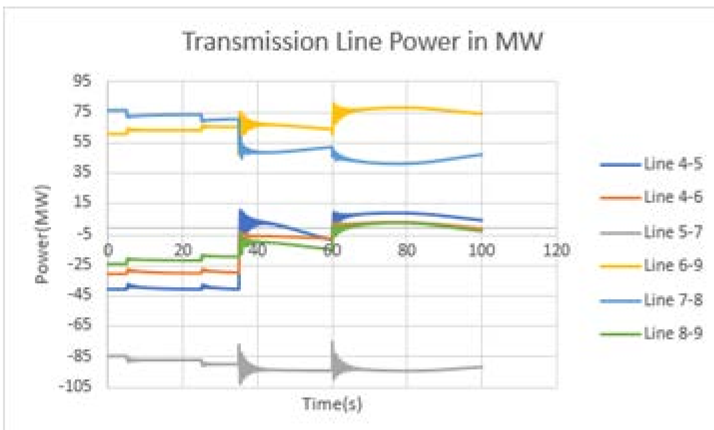

Figure 3: Power flow in the transmission line

Figure 3 shows the power flow in the transmission lines in MW. There is a decrease in the power flow in all the lines except line 5-7 and line 7-8 when the wind turbine and PV are turned on. There was a significant oscillation when the BESS was turned ON, however, the oscillation dampened after 10secs.

1.2 System response to transient symmetrical fault

Figure 4 shows how the system without DG and BESS responds to symmetrical fault on bus 6. At 5 seconds, there was a short circuit fault at bus 6 that affected the three phases. The fault lasted for 5 seconds and was cleared at 10 seconds as shown in figure 4. The fault on bus 6 caused a sharp voltage drop on all the buses. There was oscillation in the system for another 27 seconds after the fault was clear.

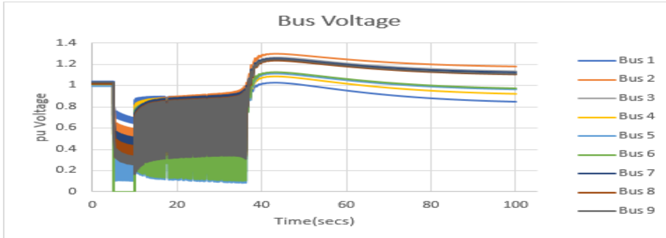

Figure 4: Bus Bar RMS voltage under a symmetrical fault

The behaviour of the system when the system was on fault for 20s is shown in figure 5 below. As seen in the figure, the oscillation lasted longer in the system after the fault was cleared.

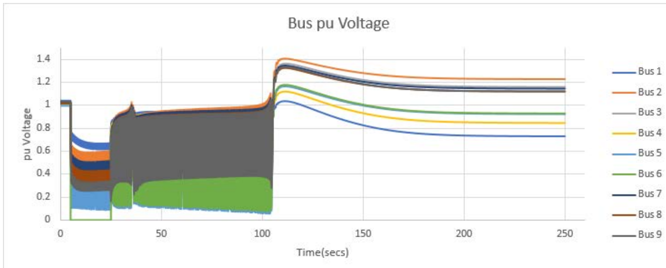

Figure 5: Bus Bar RMS voltage under a symmetrical fault

The voltage stabilized 70s after the fault cleared. However, it took 175 seconds for the voltage to stabilize when the fault duration was 20 seconds.

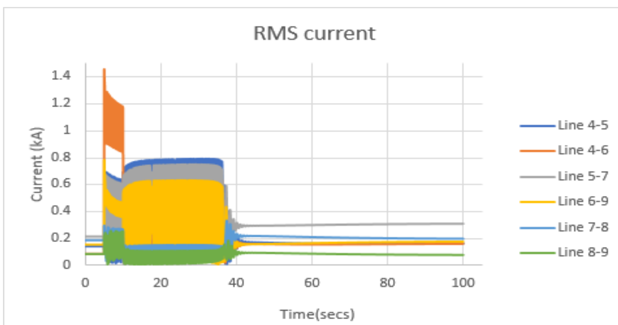

Figure 6: Transient line current under 5secs fault

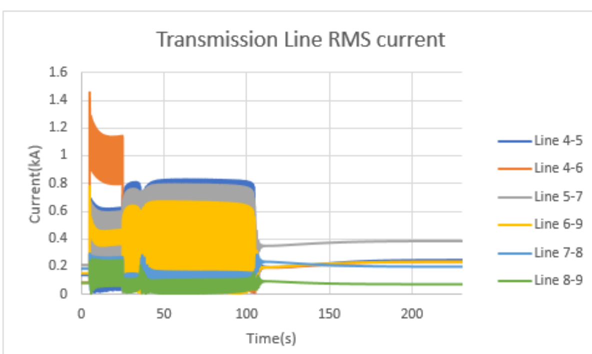

Figure 7: Transient line current under 20secs fault

Figures 6 and 7 show the behaviour of the system under a symmetrical fault condition (three-phase short circuit on bus 6) after 5 seconds. There was a sharp rise in current with bus 6 recording the highest current at the time of the fault.

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When the fault was cleared after 5 seconds, an increase in oscillation lasted for another 30 seconds. When the duration of the fault is high as shown in Figure 6 and 7, the oscillation lasted much longer even when the fault was cleared.

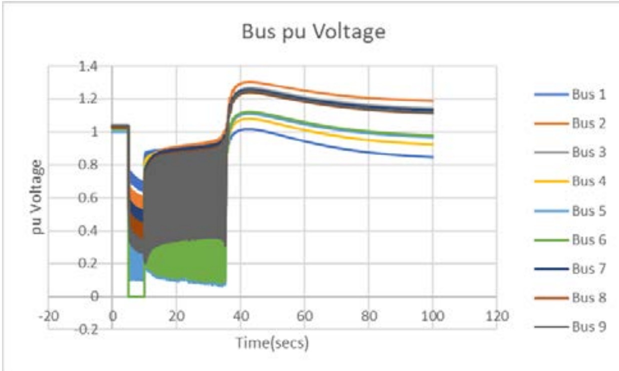

Figure 8: Bus per-unit (pu) voltage with wind turbine connected

Figure 8 shows the behaviour of the system with a wind turbine without the BESS. When there was a fault at 5 seconds that lasted for 5 seconds on bus 6, there was a sharp voltage drop in all the buses with oscillations. The bus voltages rose immediately the fault was cleared. However, the oscillations as increased but dampened out after 26 seconds.

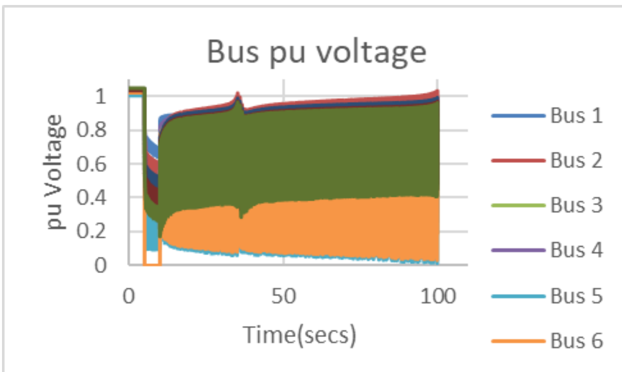

Figure 9: Bus pu voltage with PV connected

Figure 9 above shows the behaviour of the system with a PV system without the BESS. When there was a fault at 5 seconds that lasted for 5 seconds on bus 6, there was a sharp voltage drop in all the buses with oscillations. The bus voltages rose immediately the fault was cleared. However, the oscillations as increased and remained in the system even after 100 seconds.

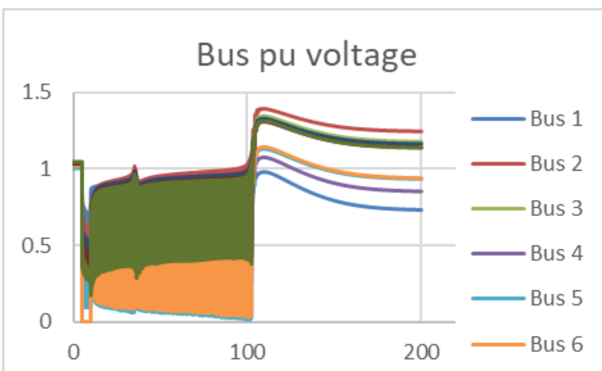

Figure 10: Bus pu voltage with PV connected after 200s

Figure 10 above shows the oscillation dampening after 105 seconds.

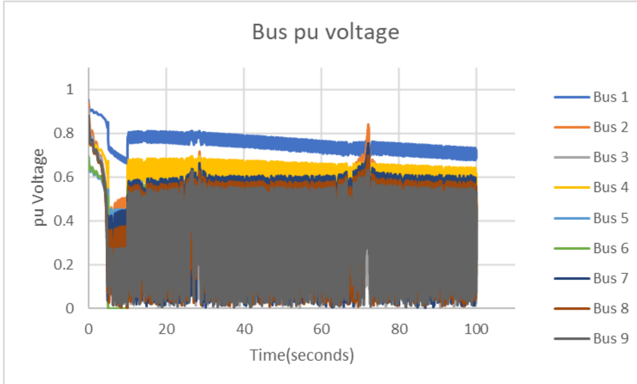

Figure 11: System (DG and BESS connected) under symmetrical fault

Figure 11 shows the behaviour of the system with DG (wind turbine and PV) and BESS. When there was a fault at 5 seconds that lasted for 5 seconds on bus 6, there was a sharp voltage drop in all the buses with oscillations. The bus voltage rose immediately the fault was cleared and remained in the system after 100 seconds

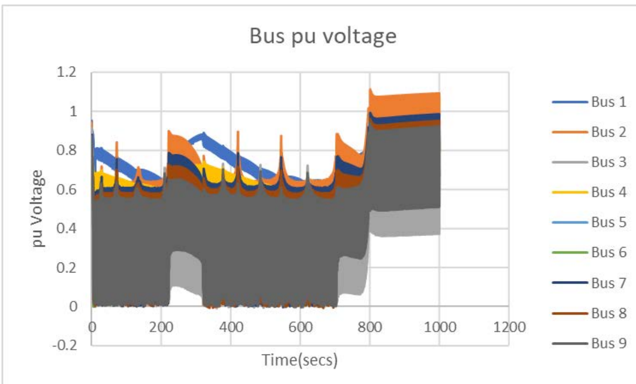

Figure 12: System behaviour under symmetrical fault after 1000s

Figure 12 above shows the oscillation remained in the system after 1000 seconds.

1.3 System response to transient asymmetrical fault

Figures 13 and 14 show how the system (with DG and without BESS) responds to asymmetrical fault. At 5 seconds, there was an asymmetric fault at bus 6 that affected two phases. The fault lasted for 5 seconds and was cleared at 10 seconds as shown in figure 4. The fault on bus 6 caused a sharp voltage drop on all the buses as shown in figure 13. There was oscillation in the system for another 32 seconds after the fault was clear and the system regained stability after being disturbed.

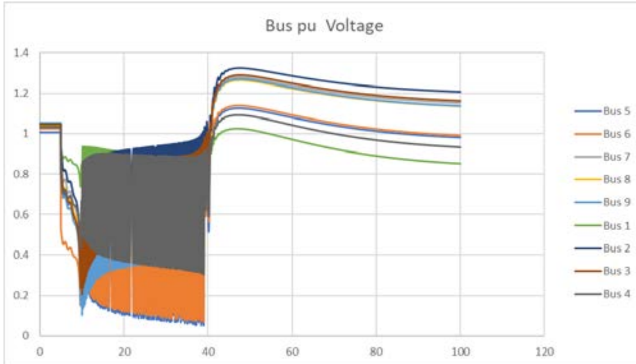

Figure 13: System (without BESS) behaviour under asymmetrical fault

However, when the BESS was connected, the oscillation does not dampen out as shown in figure 14. This makes the system is unstable.

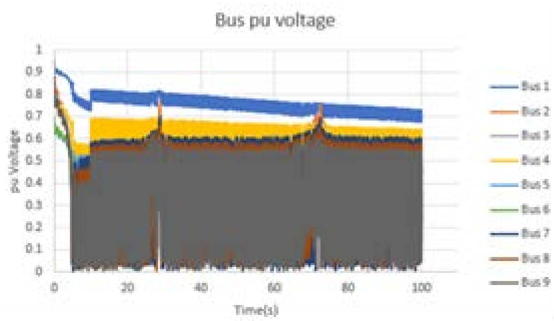

Figure 14: Behaviour of the system with BESS under asymmetric fault

1.4 System harmonic response

An industrial feeder with some energy-efficient lightings, connected to the load bus, bus 8. As expected, there was a high harmonics distortion because of the nature of the load. Figure 14 shows the simulation results of harmonics distortion at various buses of the modified IEEE 9-bus system.

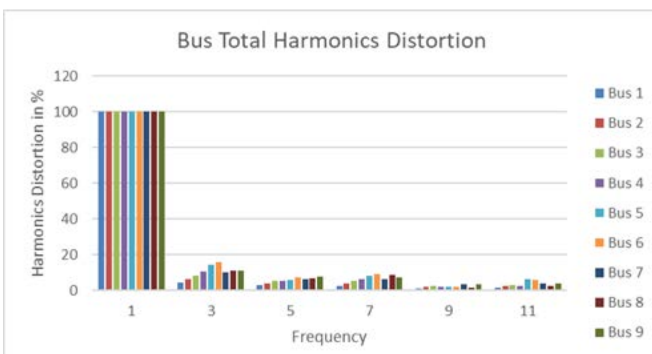

Figure 15: Total harmonic distortion of the system with BESS and DG

From the simulation, as shown in the figure above, the total harmonic distortion (THD) is relatively high at the connection points BESS, DG, and the industrial load.

Table I shows the effect of BESS and DG on the THD of the system.

	Total Harmonics Distortion (%)		
BUS	**System without DG and BESS**	**System with DG only**	**System with DG and BESS**
5	4.7	4.7	19
6	6.5	6.5	20.7
8	5.1	5.0	16.6

The BESS results in an increase in harmonics in bus 5 and 6 by 300% and 218%. However, from the table, DG improves the harmonics in the system.

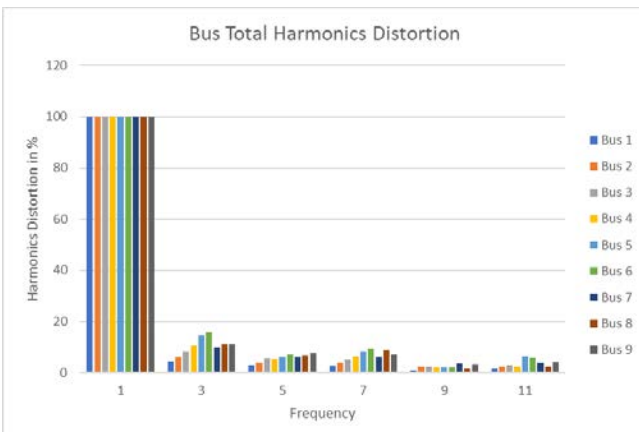

Figure 16: System harmonic distortion with DG and BESS connected

Figure 16 above shows the harmonics of the system with DG and BESS connected. The fundamental harmonics are 100% for all the buses, and other harmonics are a percentage of the fundamental harmonics. As expected, bus 5 and 6 have the highest harmonics because of the presence of BESS.

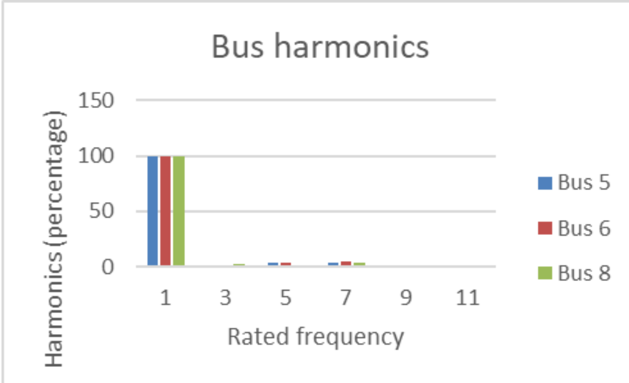

Figure 17: System harmonics without DG and BESS

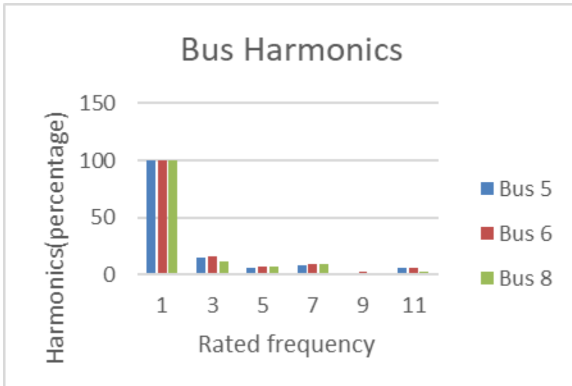

Figure 18: System harmonics with DG and BESS

As shown in figures 17 and 18, the harmonics are higher with the presence of DG and BESS

4. CONCLUSIONS

This paper evaluates the effect of DG, BESS on the stability of the modified IEEE 9-bus system during a transient. The effects of BESS and DG on the system's harmonics and the behaviour of the system was analysed under transient symmetrical and asymmetrical faults.

From the results, the system is more stable with a wind turbine than the PV system. The PV system added some oscillations to the system, which dampened eventually. Under symmetrical transient fault, the system returned to equilibrium faster if the duration of fault is low. However, when the fault duration is high, the systems take a longer time to regain stability. BESS decreases the stability of the system under both symmetric and asymmetric faults. The system harmonics improved with DG. However, BESS increased the harmonics in the system.

Faults should be cleared quickly, and circuit breaker reclosure should be with high speed for the system to remain transient stable. With the increase in attention on DG, there is need for more work in areas of reducing the harmonics in BESS system.

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